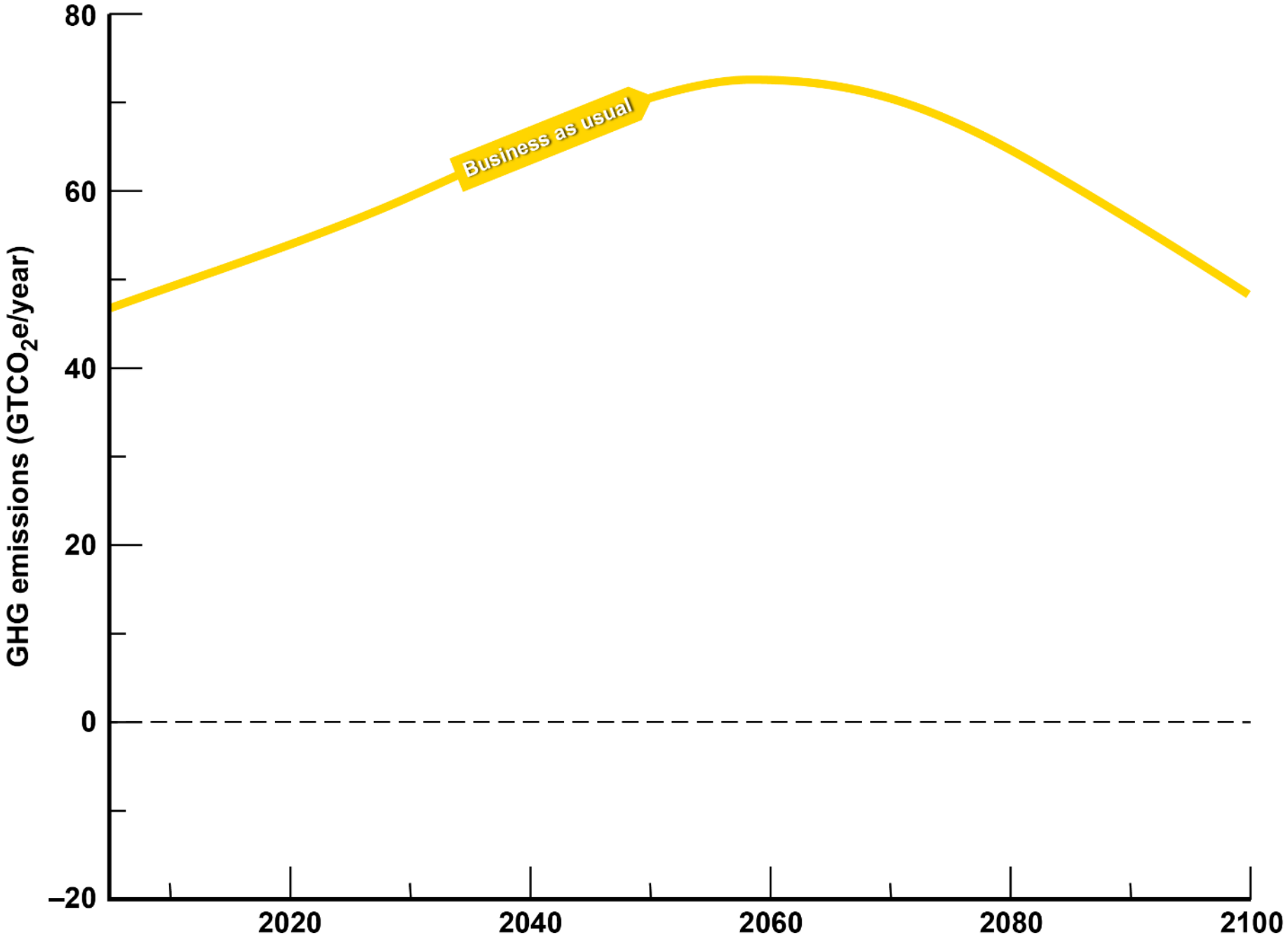
Negative Emissions: What is the Role of Minerals?

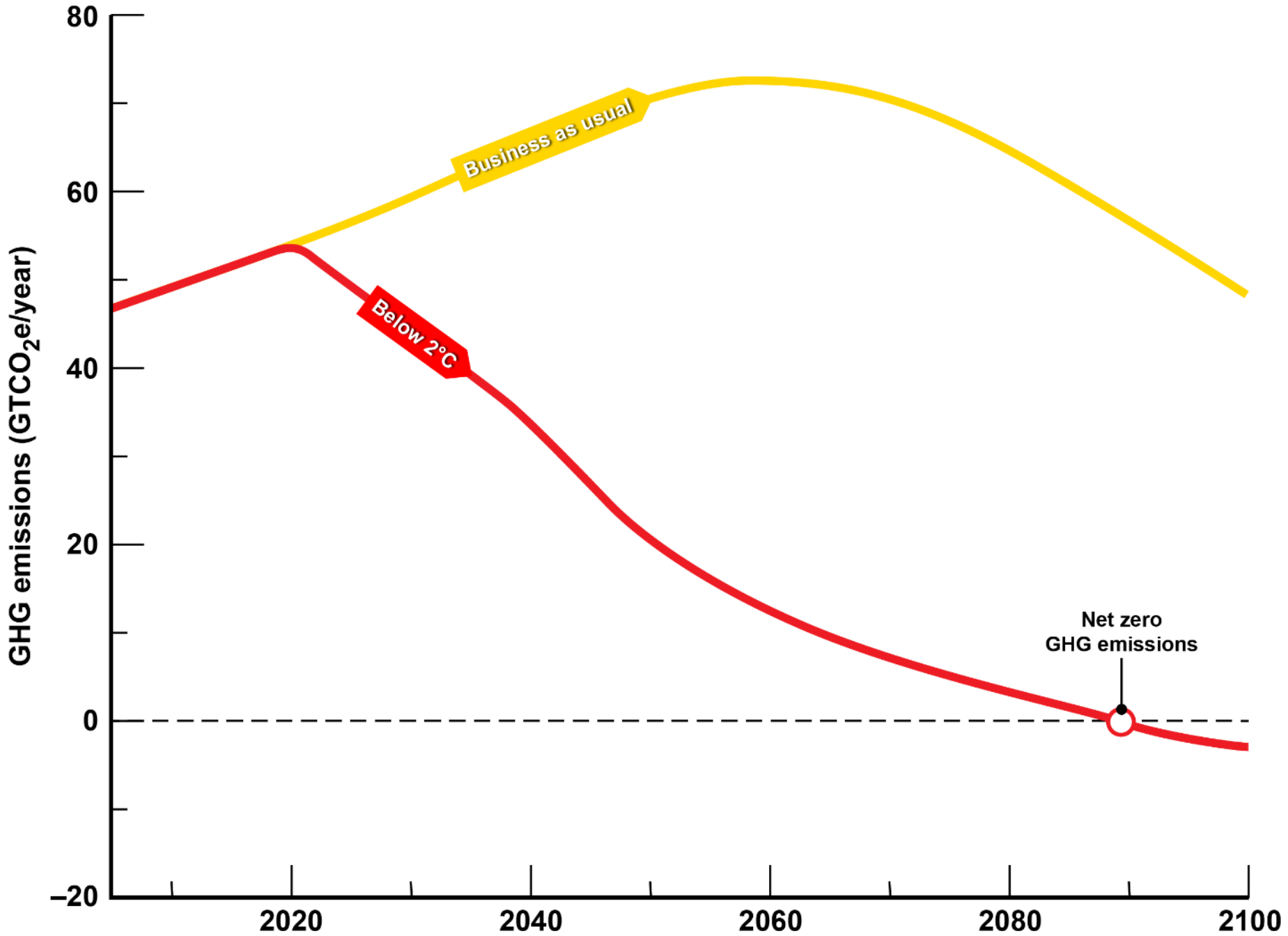
THE LLNL CARBON INITIATIVE

Roger Aines
Energy Program Chief Scientist
Lawrence Livermore National Laboratory

LLNL-PRES-795982



Source: Jérôme Hilaire Mercator Institute



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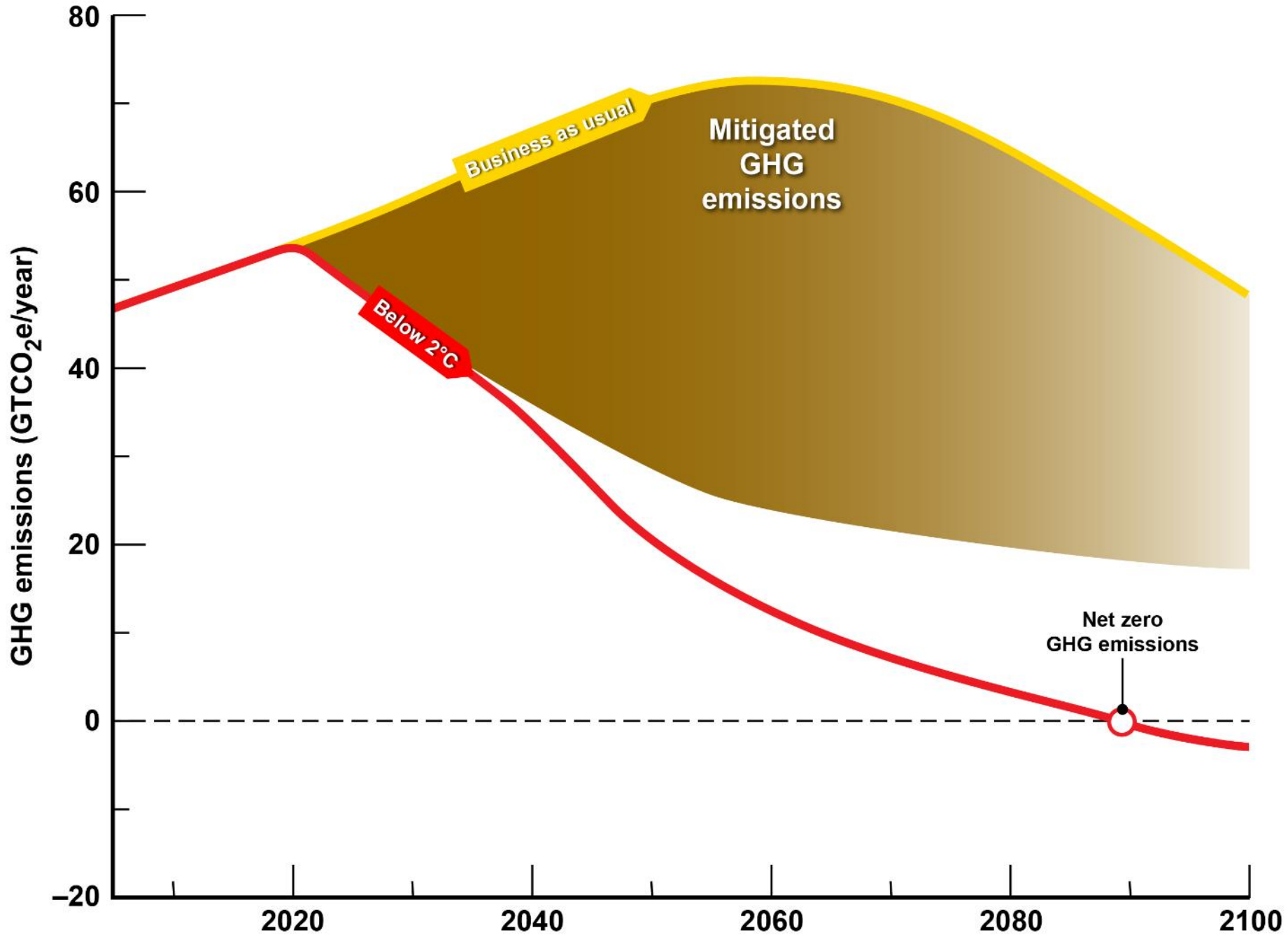

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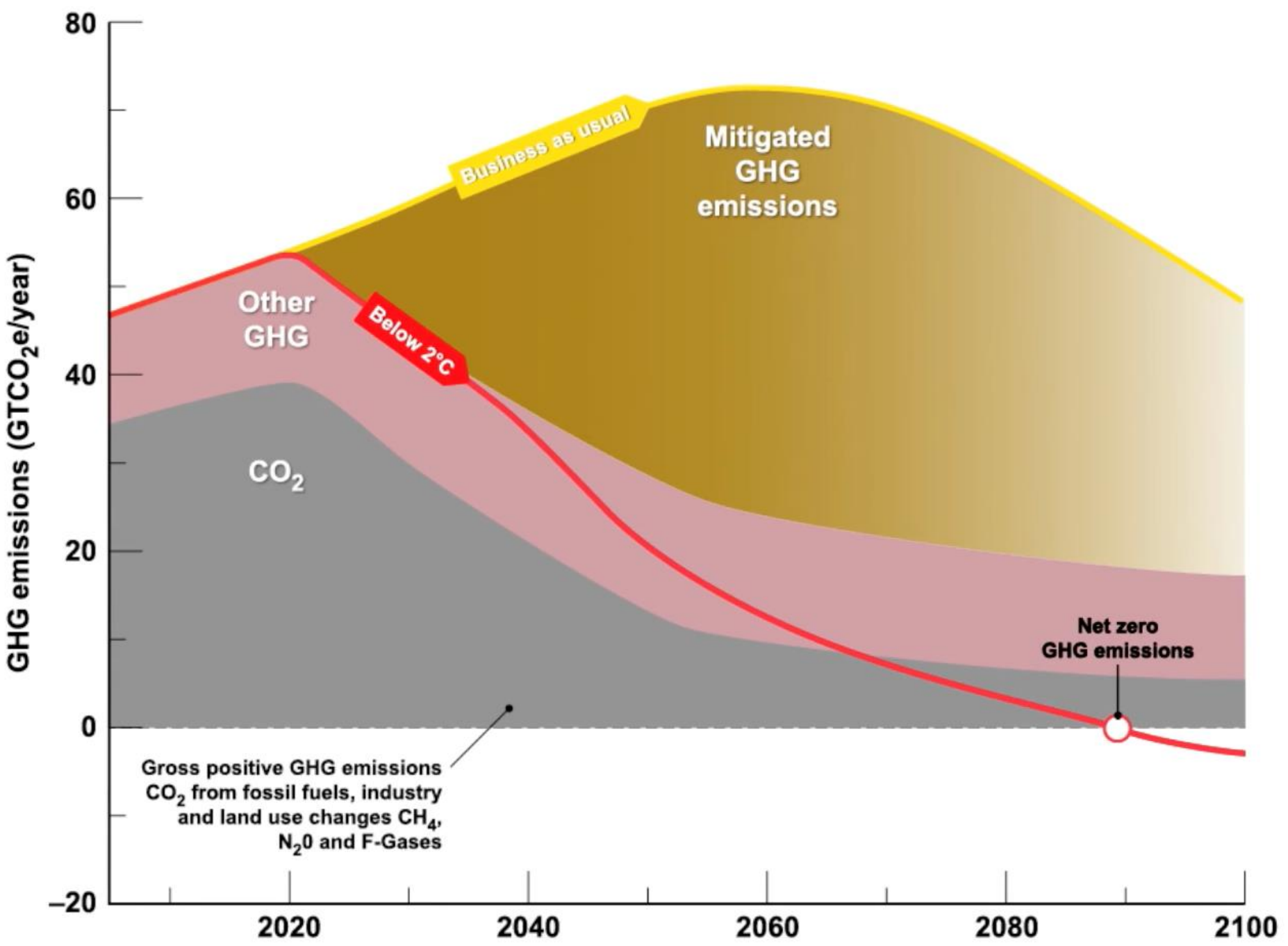

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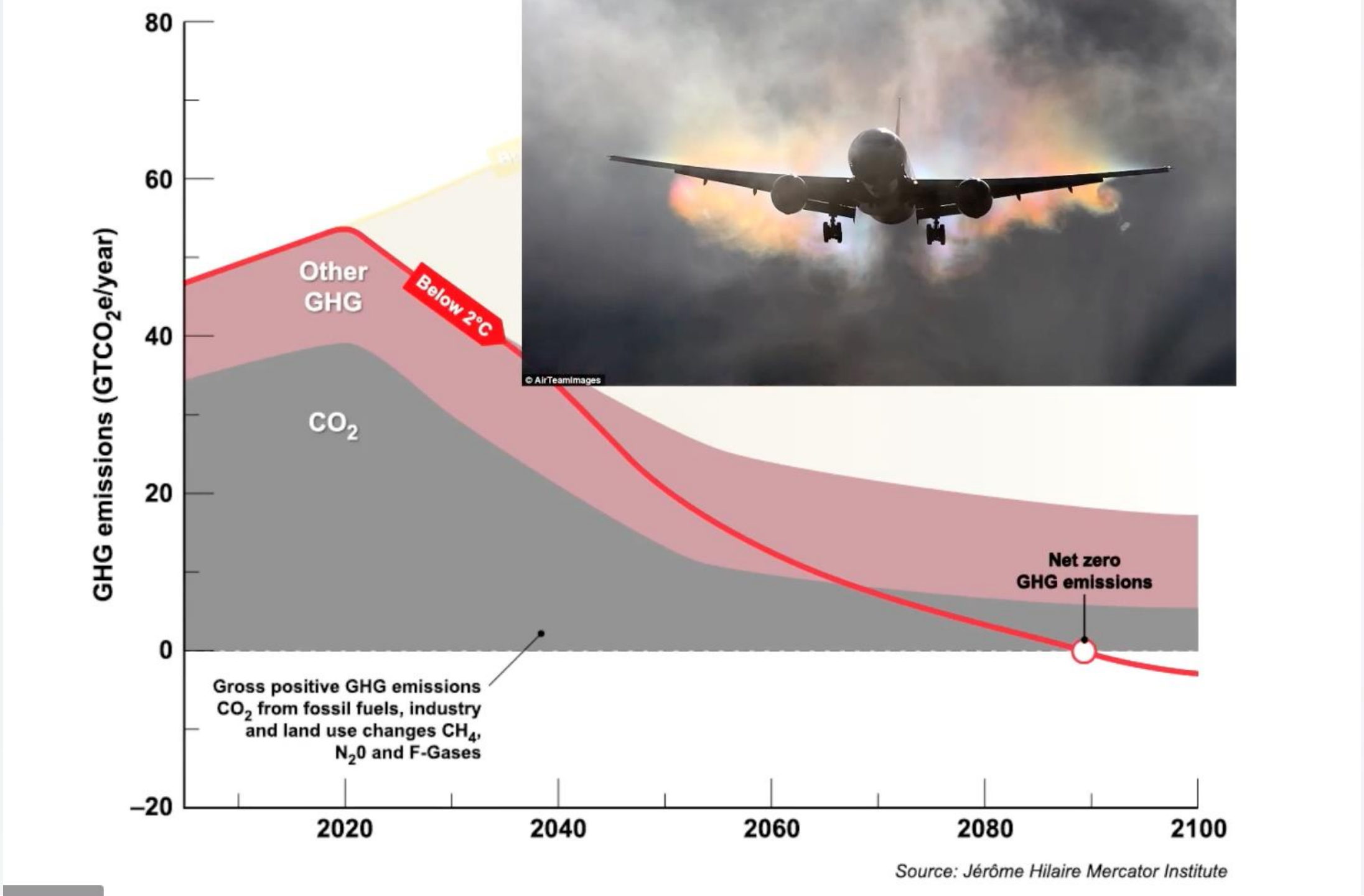
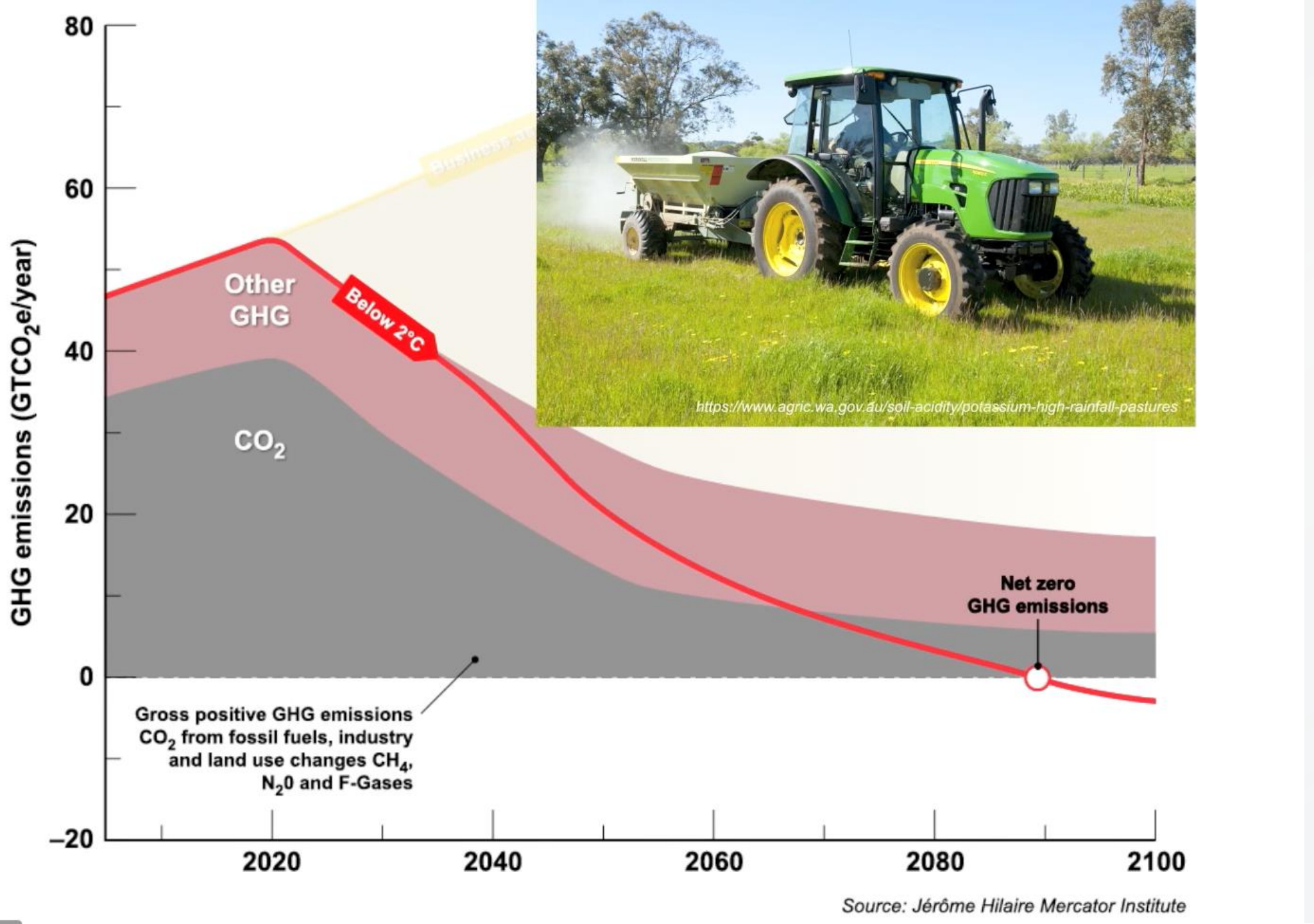

80
60
40
20
0
–20
GHG emissions (GTCO2e/year)
Other GHG
Below 2°C
CO2
Net zero GHG emissions
Gross positive GHG emissions CO2 from fossil fuels, industry and land use changes CH4, N20 and F-Gases
2020
2040
2060
2080
2100
© AirTeamImages
Source: Jérôme Hilaire Mercator Institute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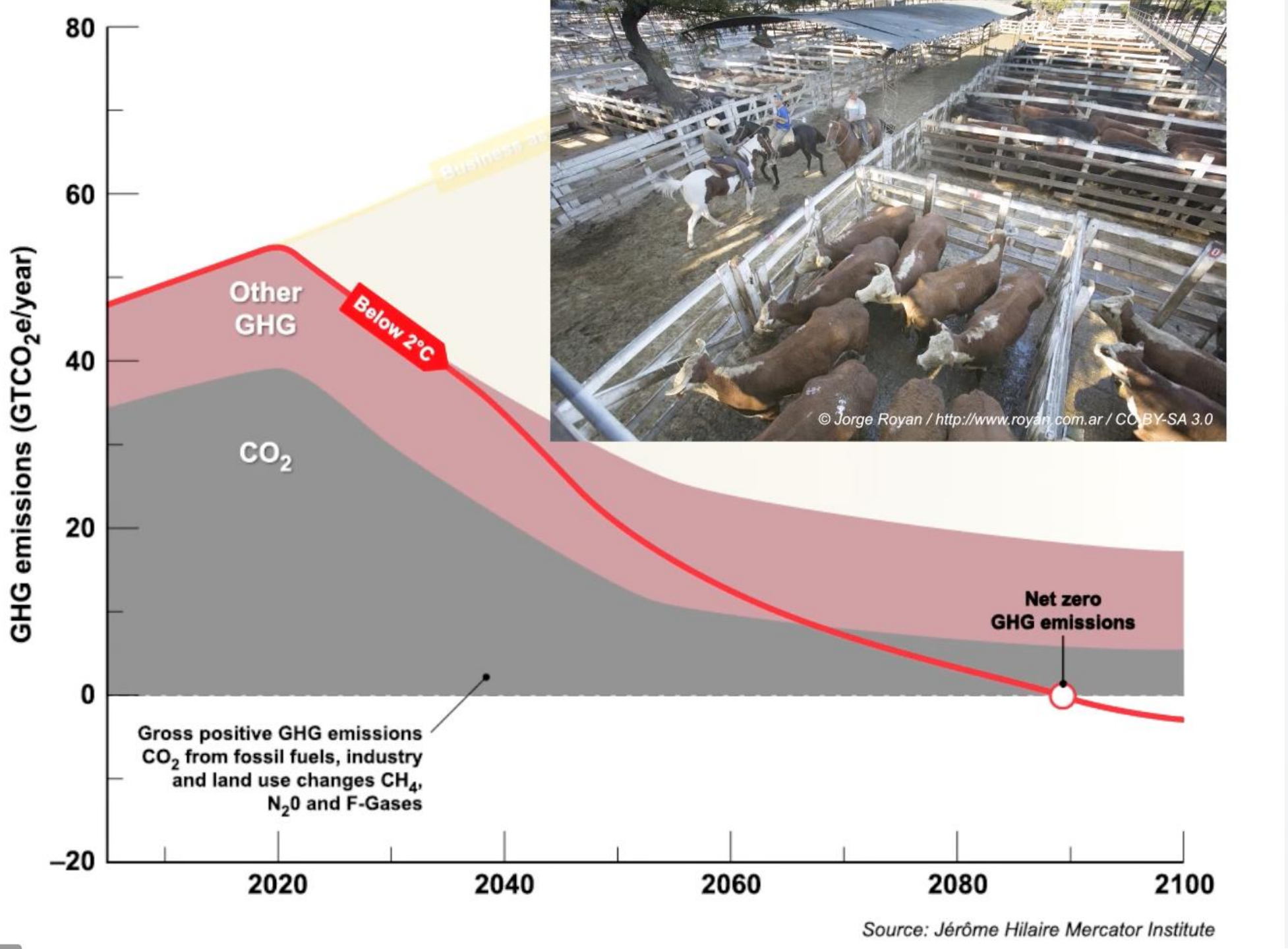
https://www.agric.wa.gov.au/soil-acidity/potassium-high-rainfall-pastures
Source: Jérôme Hilaire Mercator Institute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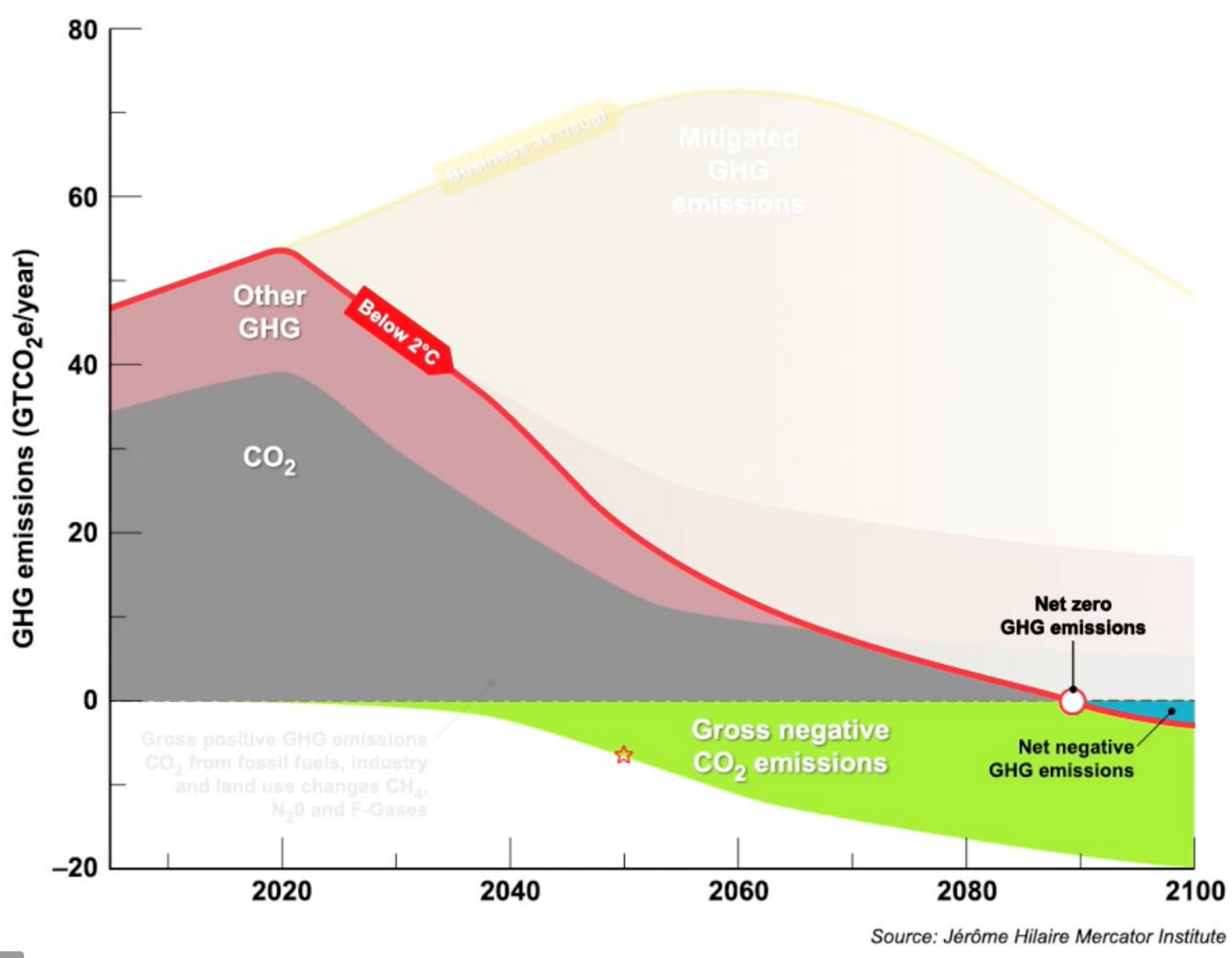
Source: Jérôme Hilaire Mercator Institute



Reductions
In Emissions

Removals
From the Air

We love to think globally, but most actions will be local

Overall economy or region

- Academics love this perspective “optimal”
- Carbon tax is the preferred tool from this view

Business

- Net zero is the common goal
- Must deal with your own emissions, your suppliers, and customers
- Need specific pathways

Sector (like transportation)

- Mixture of the first two – easier to make clear policy

Microsoft

CALIFORNIA
AIR RESOURCES BOARD

Net zero ambitions are growing rapidly

Most by 2050, and a few by 2035

60% of current emissions are covered by a net zero ambition

~~22~~ 34 Nations and Regions

Canada
South Korea
Denmark
France
Switzerland
US
China
New Zealand
Austria
Germany
EU
UK

13 States

California
New York
Washington
Virginia
Maine
Virginia
Colorado
Nevada

1100 Businesses

Microsoft
Amazon
Unilever
Mercedes-Benz
Occidental
BP
Southern Company
Apple
Ford
Maersk
Nike
Total
Shell

How can we remove CO_2 from the air?


Trees
Often a promissory note

Net carbon emissions from Canada's managed forests

The effects of fire and infestation result in net carbon emissions

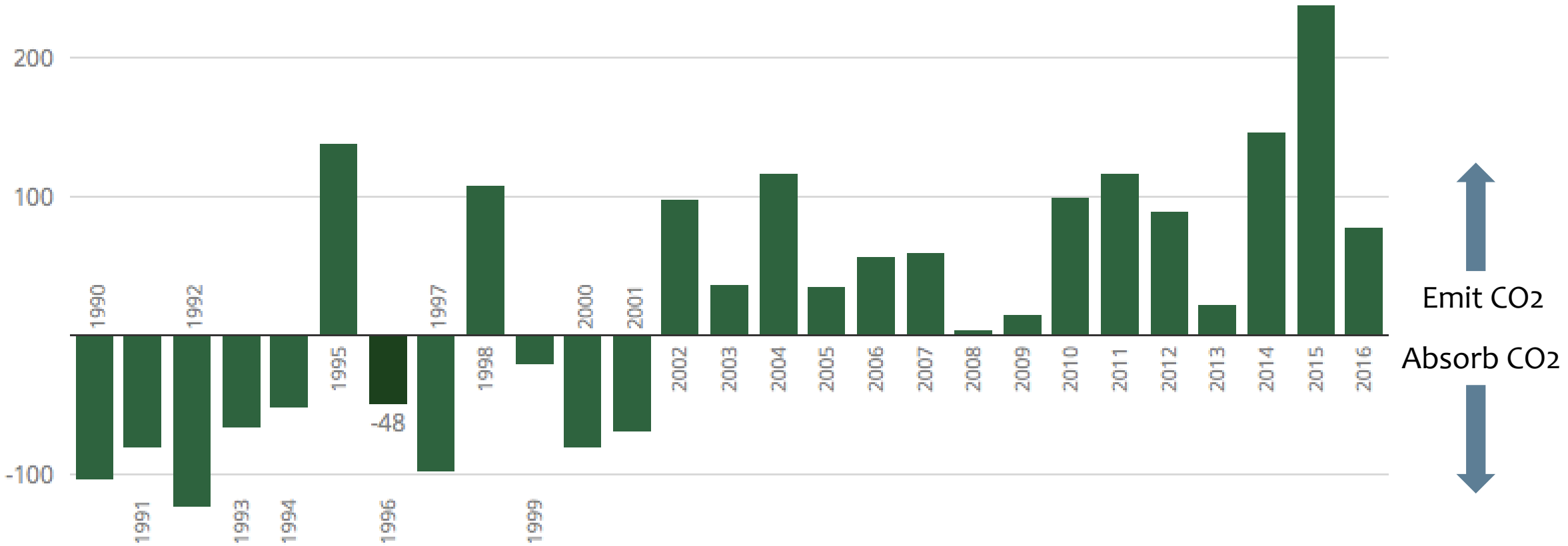


Chart: Robson Fletcher / CBC • Source: Natural Resources Canada

cbc news

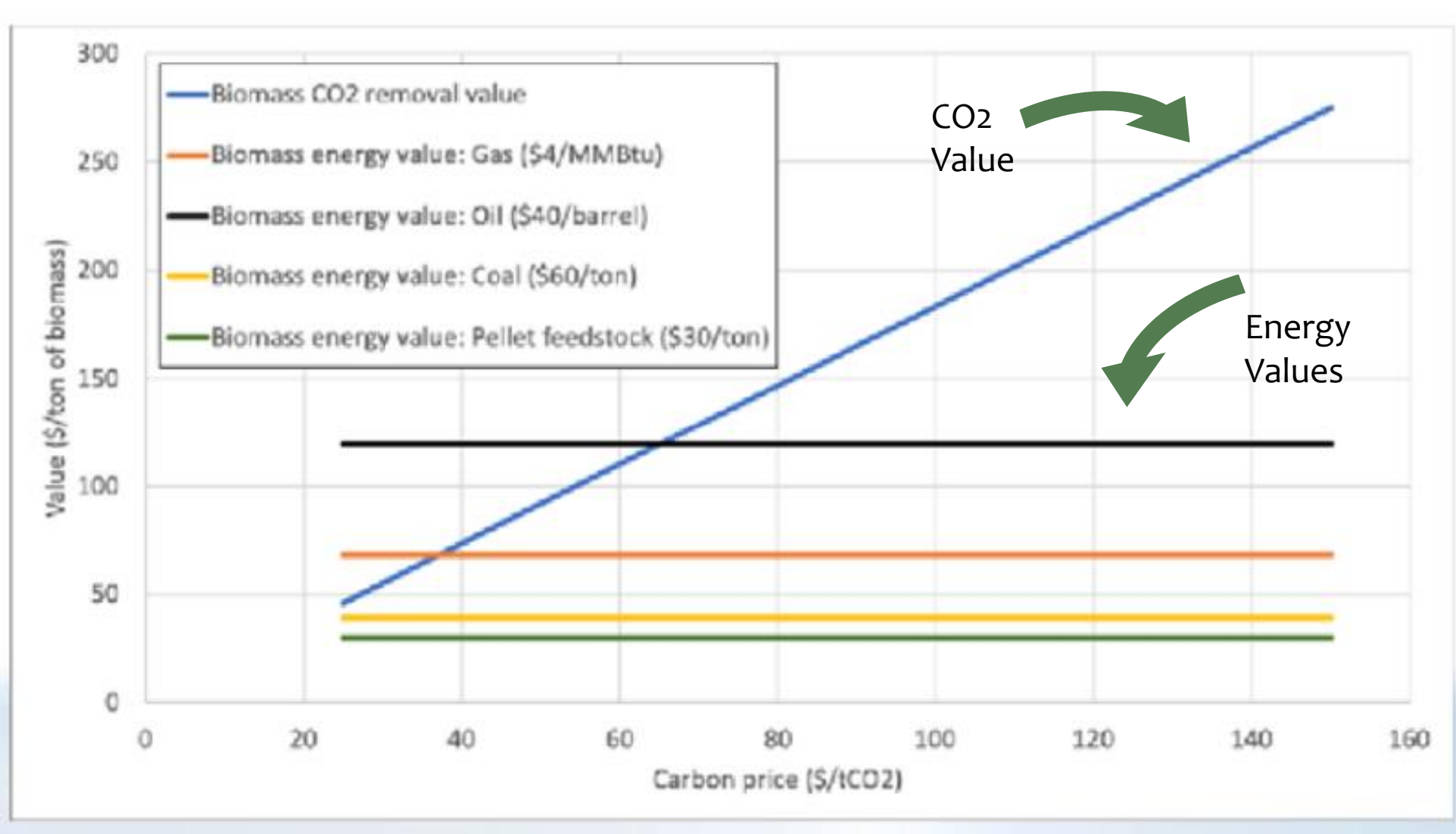
Using biomass *waste* is a great place to start

Todd Nishikawa, Placer County Air Pollution Control District

BioEnergy with Carbon Capture and Storage: BECCS

Burning biomass must be restricted to true waste – but there is a lot of that

The carbon removal value of biomass exceeds its energy value at realistic carbon prices



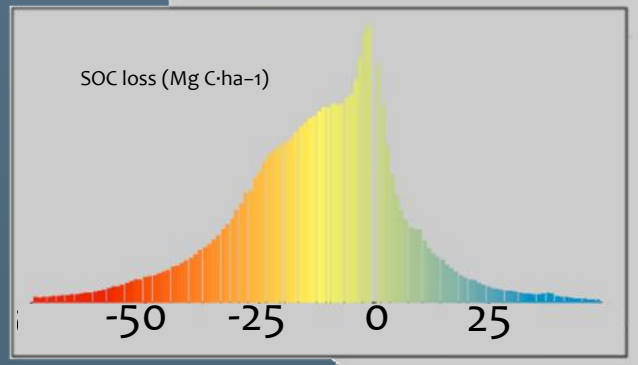
Soils

Gigantic capacity, but how fast?

The world's farm soils have lost at least 487 gigatons of CO_2 (equivalent).

Can we put it back?

How fast?



Sanderman et al. 2017

We could build machines to clean the air

Opportunity:

Heat is 75% of the energy cost of direct air capture. Use cheap heat.

1000 ton per year capture facility, Zurich

Much of the removed CO_2 will have to go back underground.

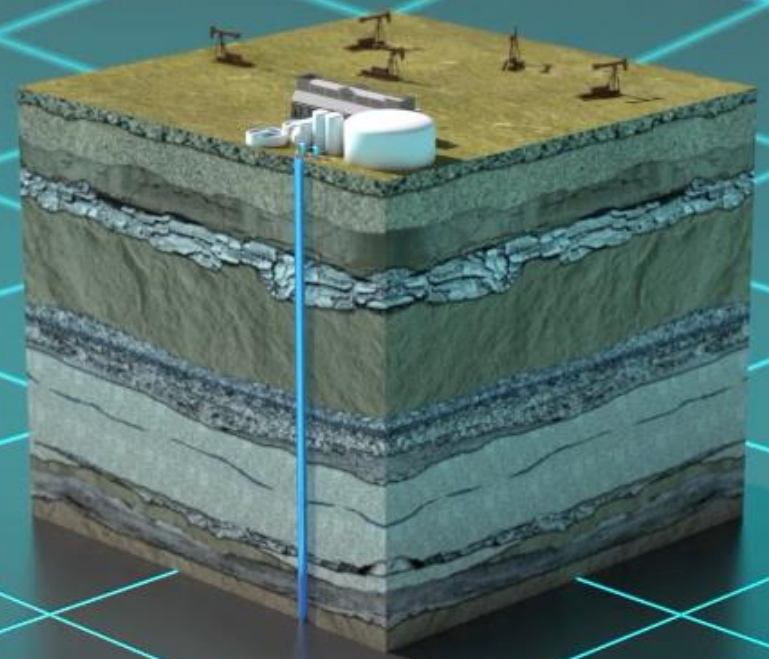
CO_2's properties are very similar to oil.

It can be stored in the same places.

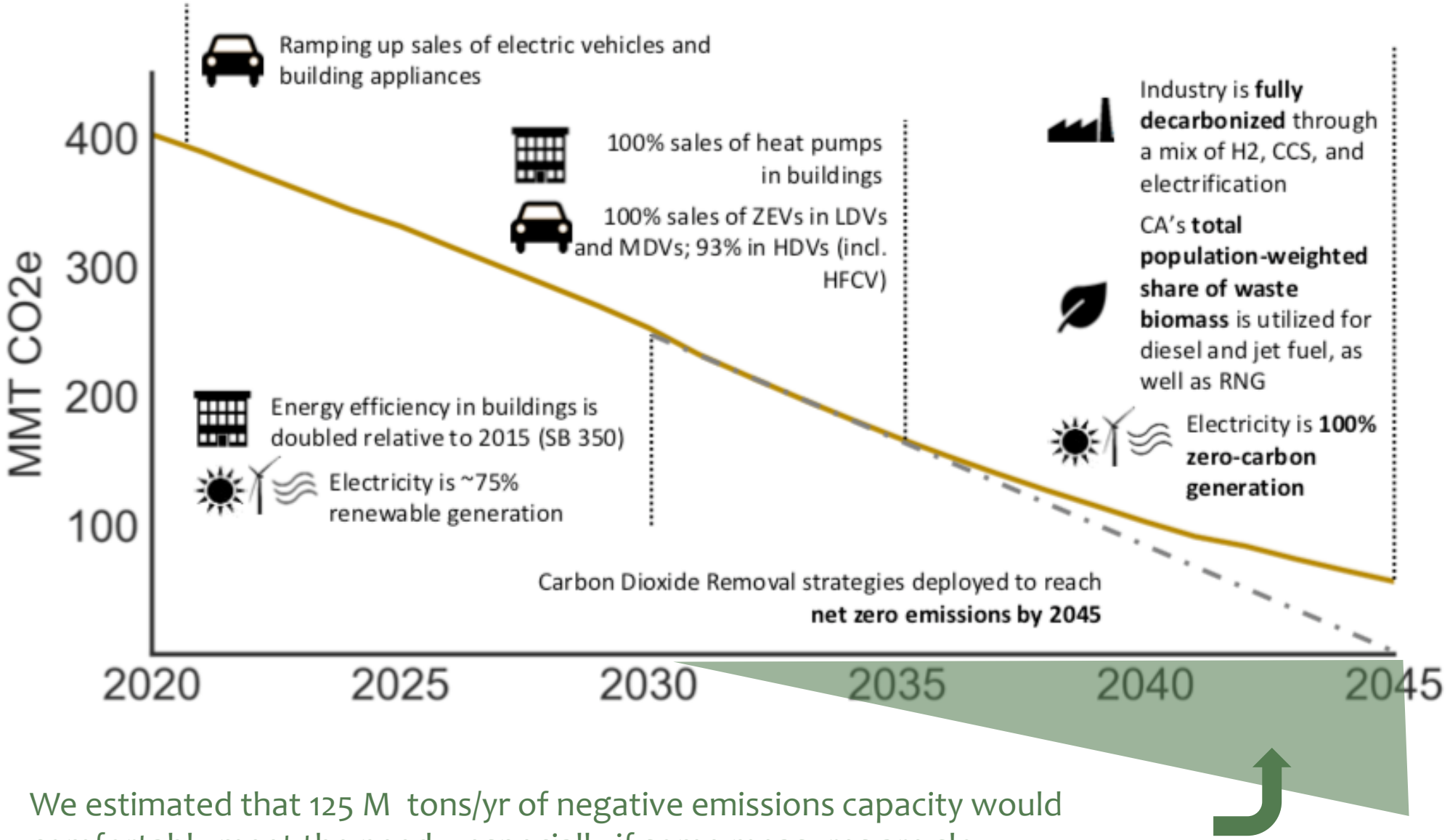
The technology, people, and jobs are the same for both.

The sunset of the oil age can also be the rise of the storage age.

Geologic Storage: Liquid CO_2 at Great Depth



California's Path to Zero



We estimated that 125 M tons/yr of negative emissions capacity would comfortably meet the need – especially if some measures are slow.

How can California achieve 125 MT/year of negative emissions by mid-century?

- Natural and Working Lands

25 MT/year

- Waste Biomass Conversion to Fuels with CO_2 Storage

Todd Nishikawa, Placer Cty Air Pollution Control District

83 MT/year

- Direct Air Capture with CO_2 Storage

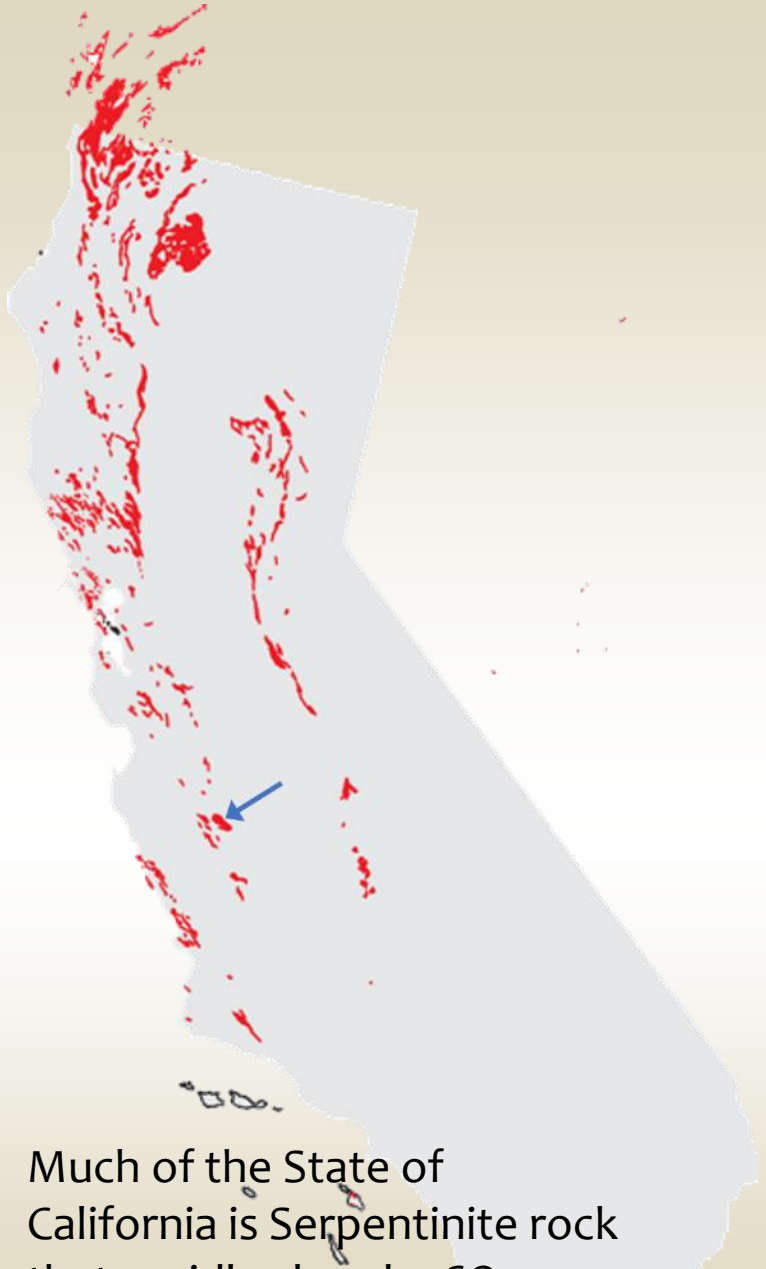
17 MT/year

Technological readiness: mid-to-high – no new breakthroughs required

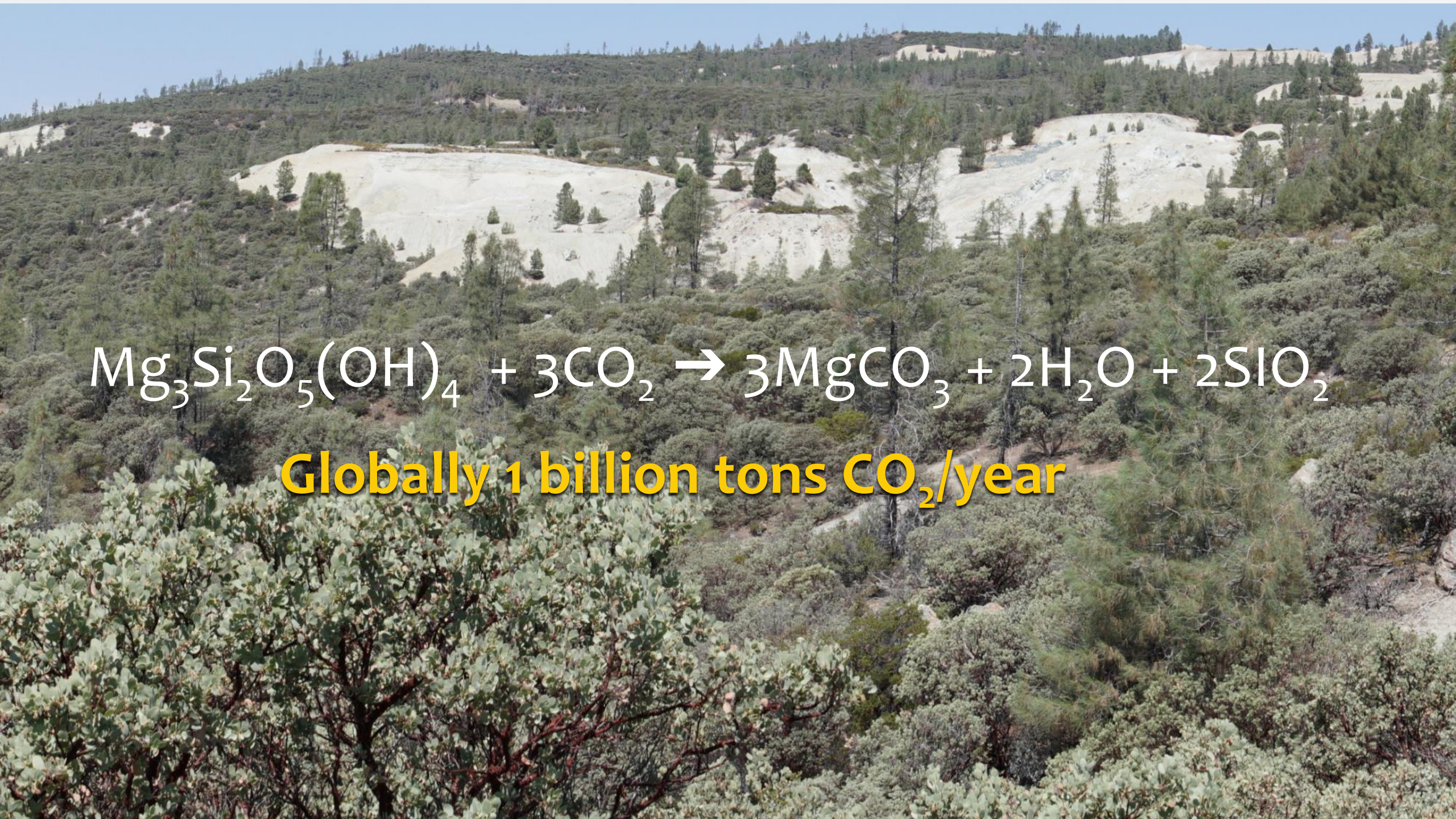
Mineralization: huge range of observed rate of reaction

Need #1

Standard tests and reference materials for that reflect reactivity and structure



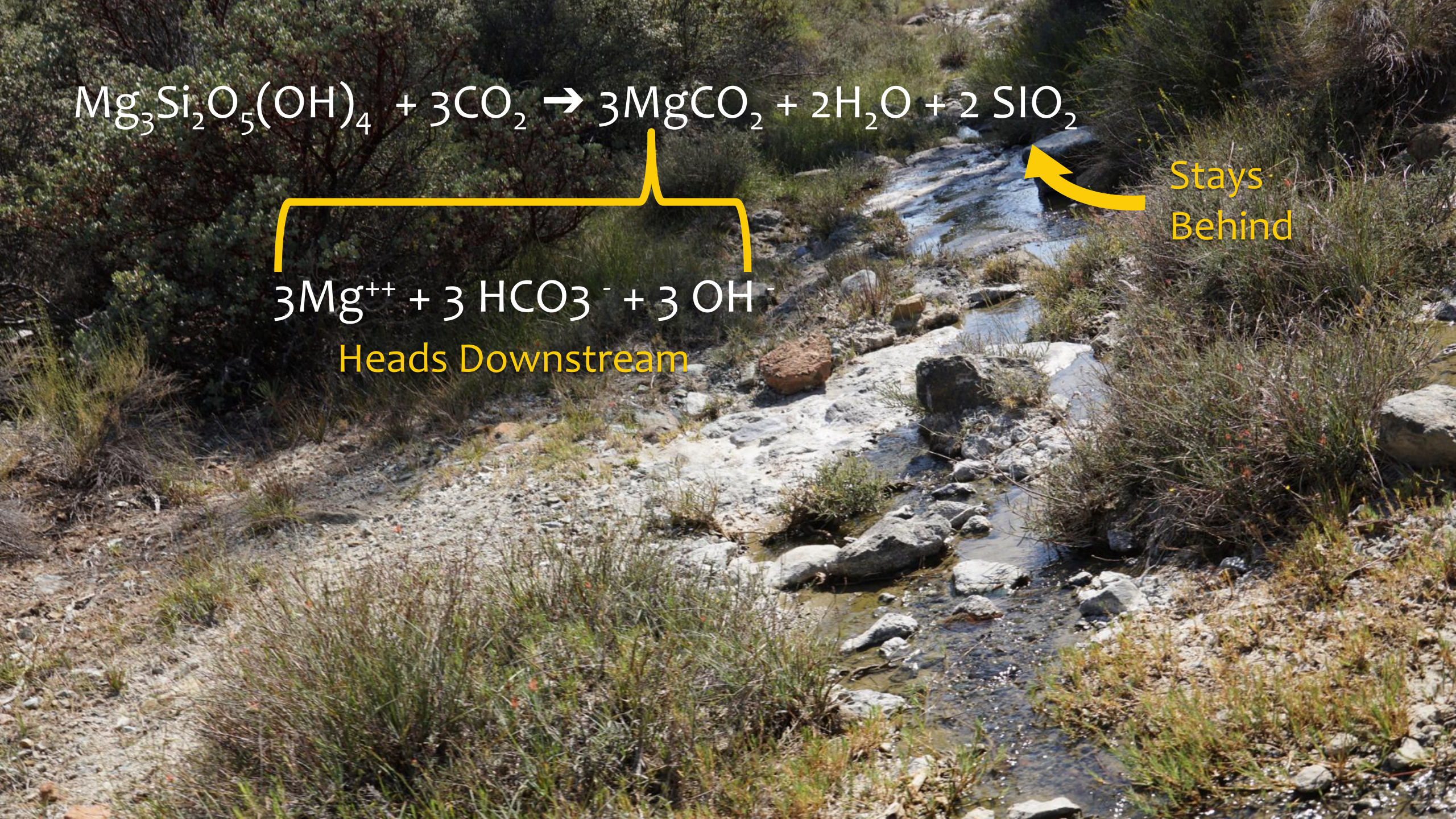
Much of the State of California is Serpentinite rock that rapidly absorbs CO_2

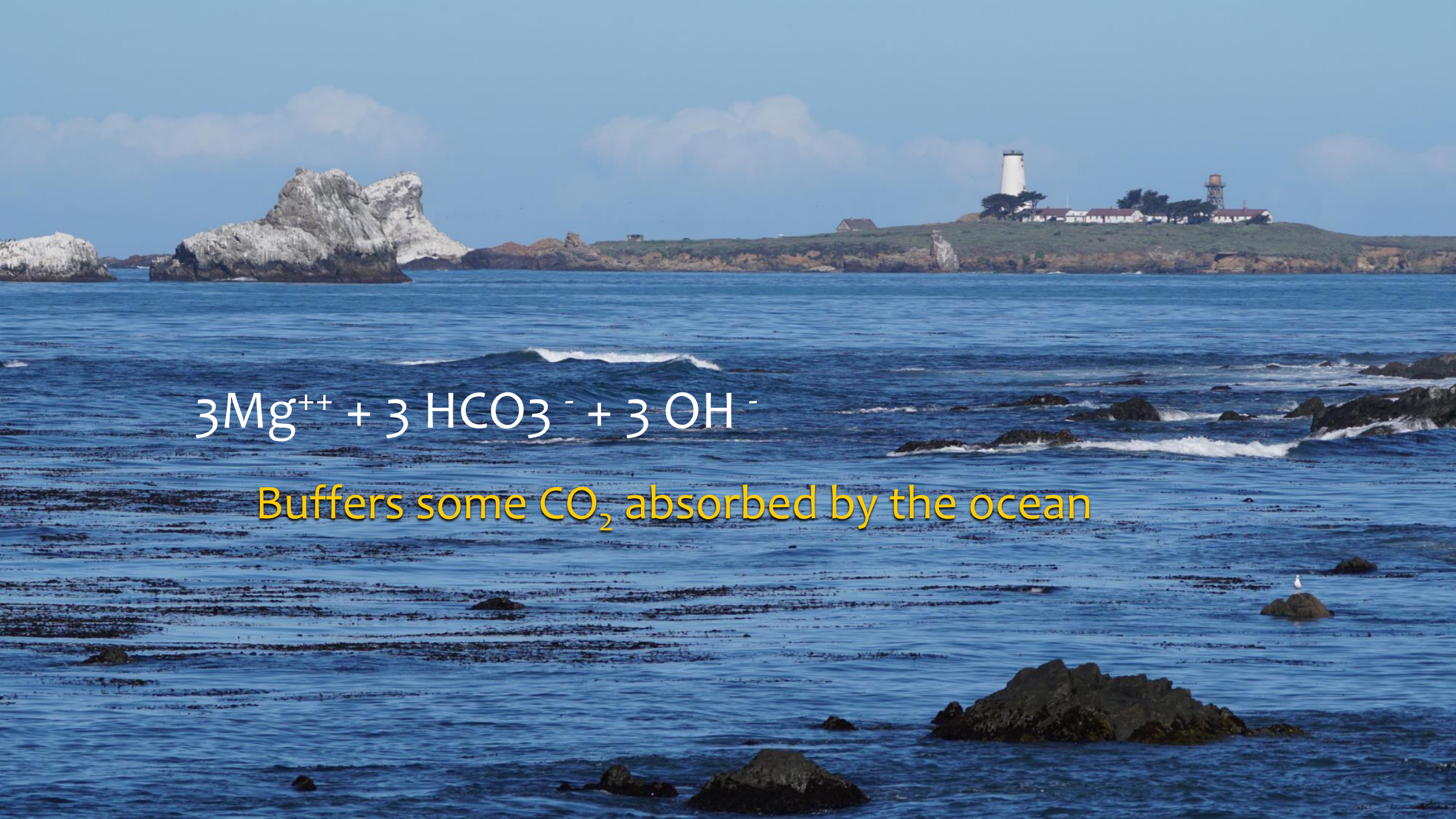

$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_3 + 2H_2O + 2SIO_2$
Globally 1 billion tons CO_2/year

Safety

Most rocks of interest can have asbestos and heavy metals.

These are treated VERY differently by locale


$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_2 + 2H_2O + 2\ SIO_2$
Stays Behind
$3Mg^{++} + 3\ HCO3^{-} + 3\ OH^{-}$
Heads Downstream


$3Mg^{++} + 3\ HCO3^{-} + 3\ OH^{-}$
Buffers some CO_2 absorbed by the ocean

CDR Status

Ready to Scale (at a price)

Close

Major R&D

DACCS	**Three major developers, ~ 20 minors**	**$700** **Rate of scale up and supply of renewable energy**
Forestation	**Questions about additivity, timing, and availability limit scale**	**$25 – 30** **Reflects high quality projects in countries with strong regulatory frameworks**
BiCRS ≠ BECCS	**Waste biomass operated for maximum carbon removal. Includes biochar.**	**$50 – 200** **Supply chain and CO2 storage uncertainty.**
Soil Carbon	**Monitoring and lifetime need to be established**	**$0 – 400** **Recurrence time sensitivity**
Mineralisation, Enhanced Weathering	**Mostly strong concepts – few demonstrations**	**~$20-1000** **Price uncertain, set to drop with scale of deployment**
Seaweed	**Concept stage**	**??**


Keep a Big Tent
Learn to like lots of approaches.
Embrace all the technologies and approaches necessary to fully decarbonize the economy.